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(54) Abstract Title
Flow control apparatus and method

(57) A method for obtaining equalized production from deviated wellbores comprising a plurality of spaced apart flow control device 20a-n which are deployed along the length of the wellbore 14. Each control device includes a flow valve 24a-n and control units 26a-n to control flow output from the flow control device. The control unit may communicate with surface equipment 50 or act autonomously to take actions downhole based on programmed instructions provided to the control unit. The fluid from various zones Z_1-Z_n are drawn in a manner that depletes the reservoir uniformly along the entire length of the wellbore. Each flow control device is initially set at a rate determined from initial reservoir simulations or models. The depletion rate, water, oil and gas content, pressure, temperature and other desired parameters are determined over a time period. This data is utilised to update the initial reservoir model, which in turn is utilised to adjust the flow rate from one or more zones so as to equalize the flow rate from the reservoir. The present invention also provides a flow control device which includes an outer shroud (fig2B,235) that reduces the effect of fluid impact on the flow control device and one or more tortuous paths (fig2A,214) which carry the formation fluid into the production tubing (fig2A,220).

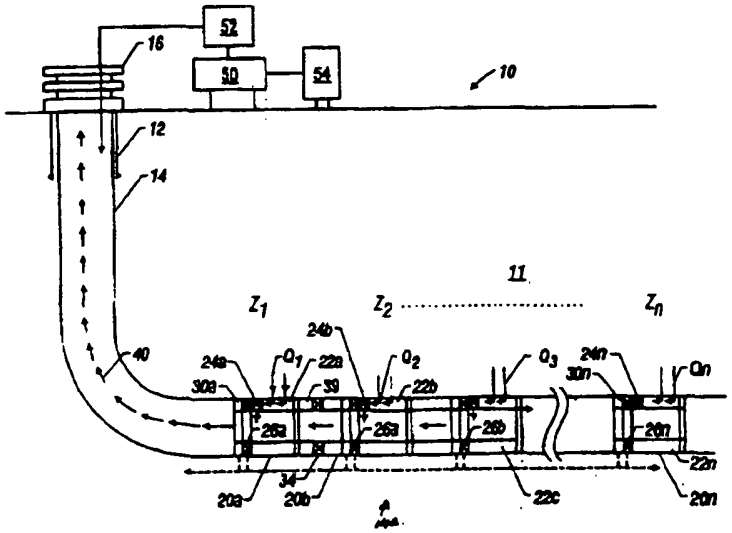

Figure 1

GB 2 325 949 A

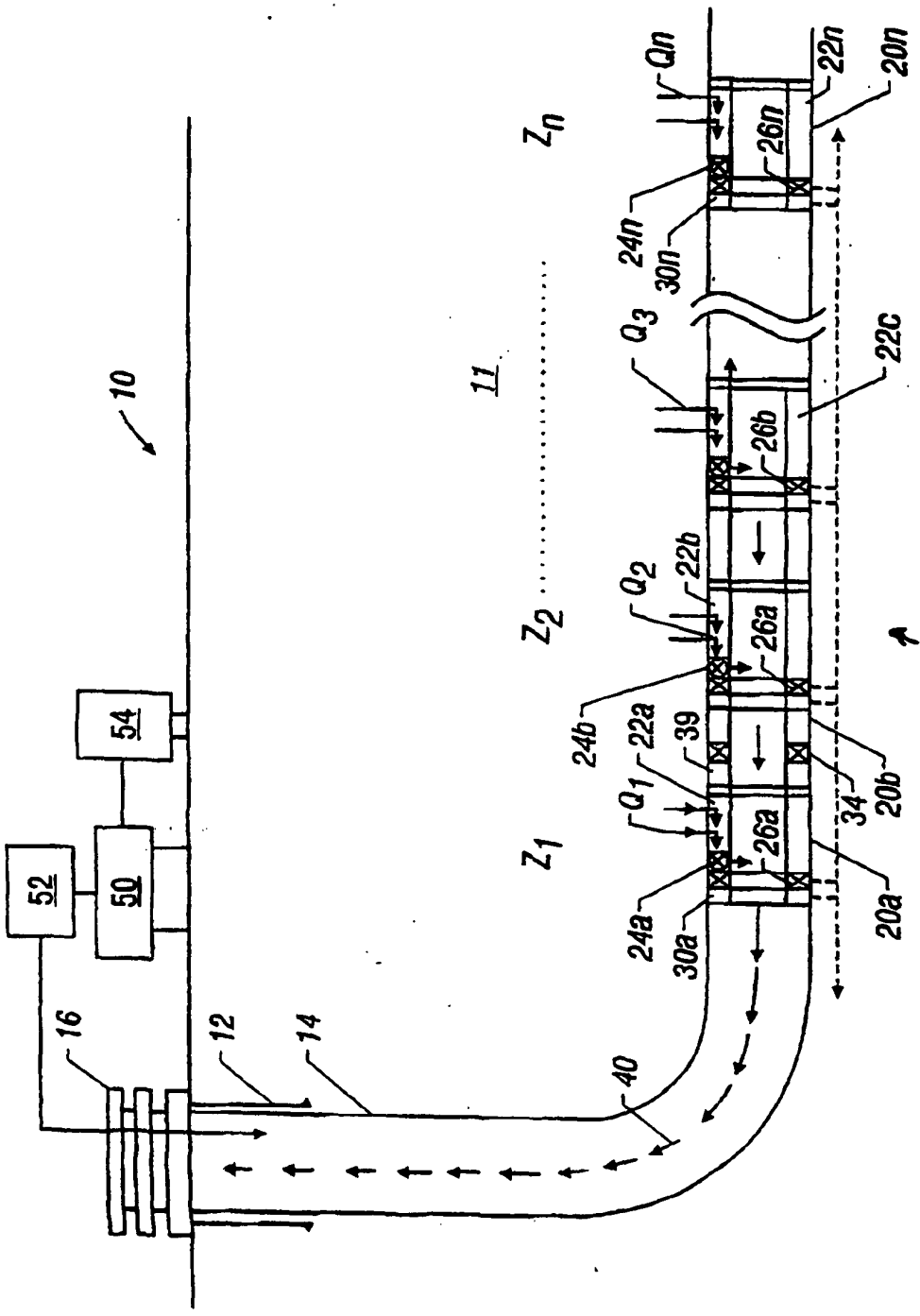
10
11
52
50
54
16
12
14
40
Z_1
Z_2
Z_n
Q_1
Q_2
Q_3
Q_n
22a
22b
22c
22n
20a
20b
20n
24a
24b
24n
26a
26b
26n
30a
30n
34
39

Figure 1

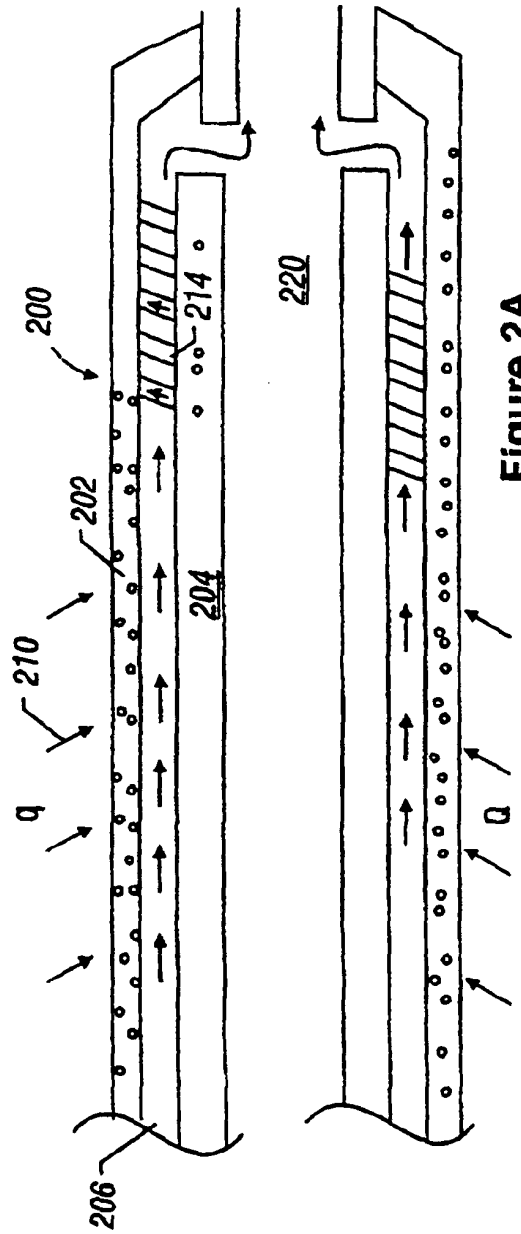

Figure 2A

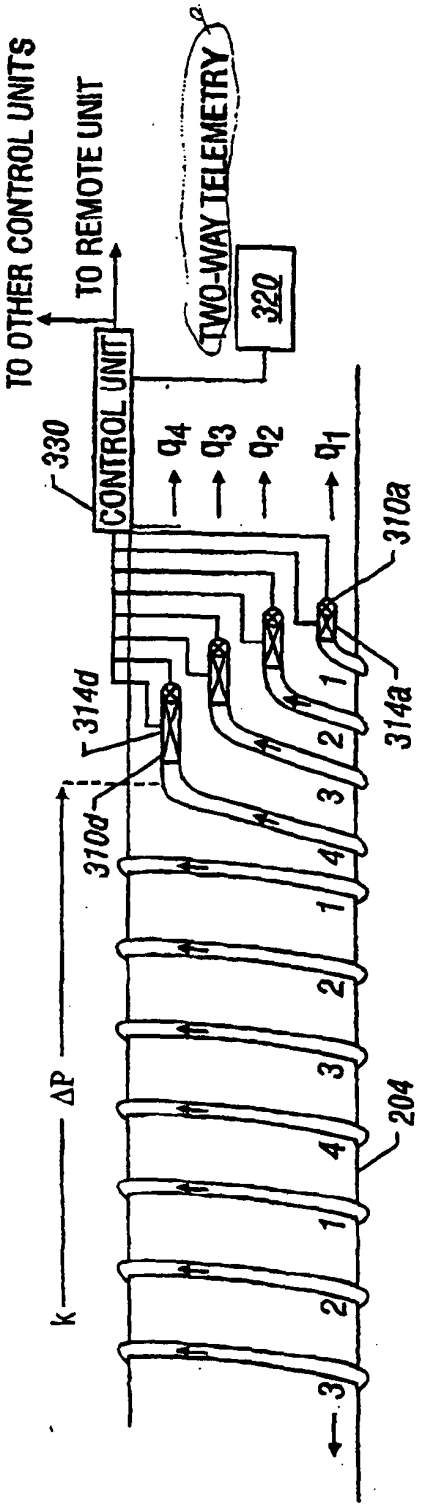

Figure 3

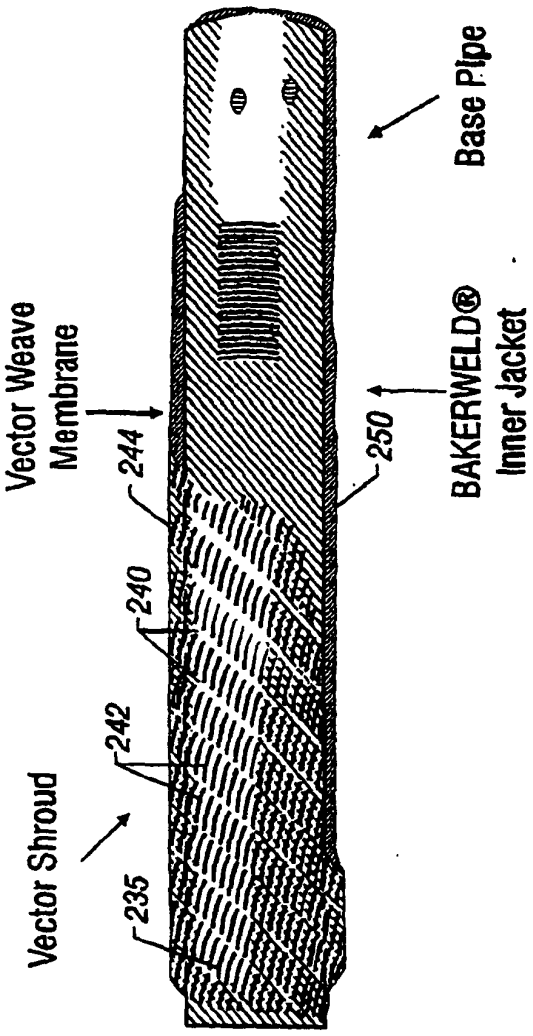
Base Pipe
BAKERWELD®
Inner Jacket
250
Vector Weave
Membrane
244
240
242
Vector Shroud
235

Figure 2B

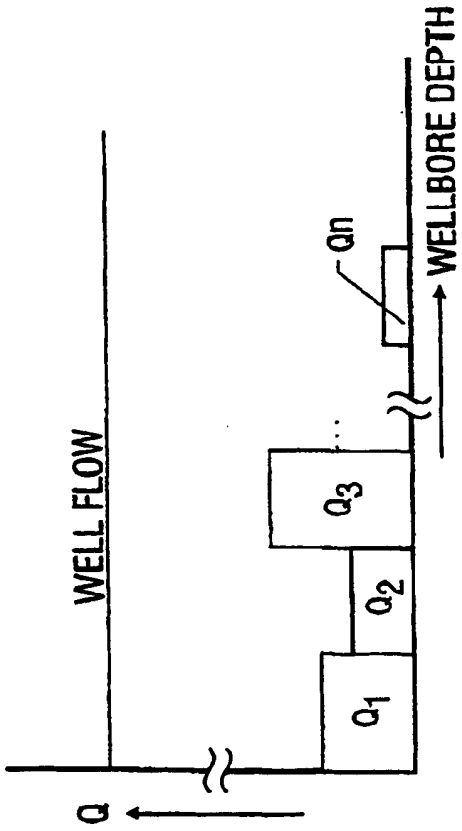

Figure 4

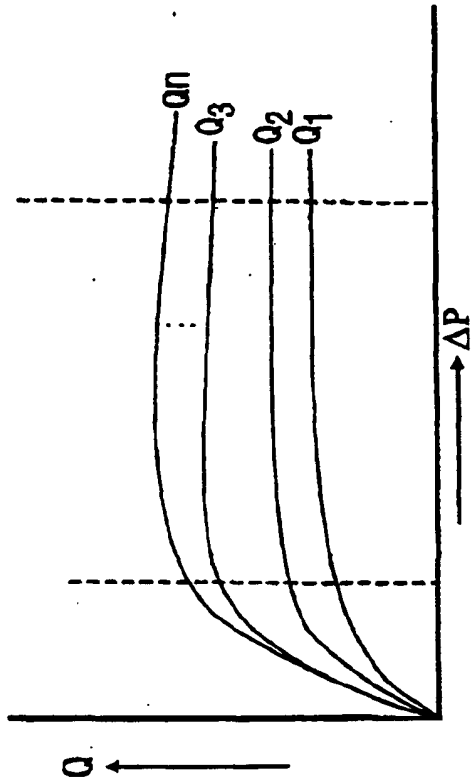

Figure 5

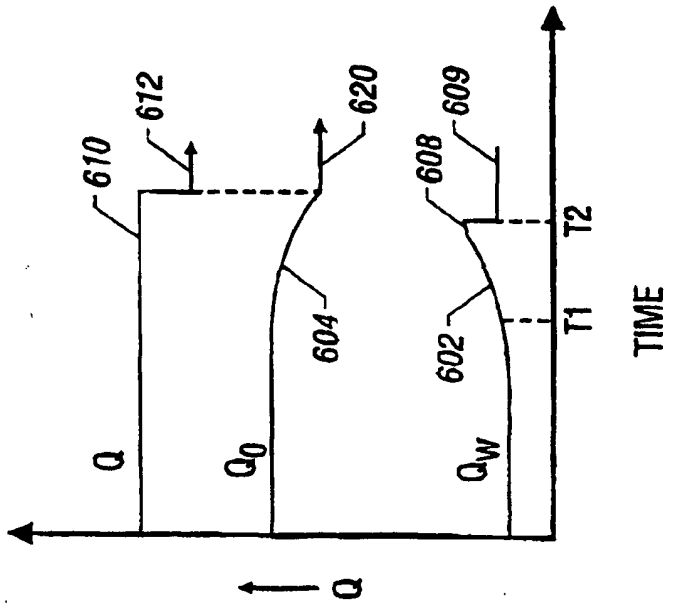

Figure 6

Horizontal Well with Permeability Contrasts and Shale

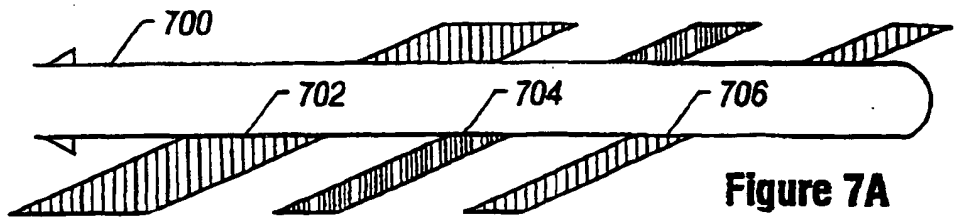

Figure 7A

High Permeability | Shale Section | High Permeability

The well has been drilled, logged and geophysical map has been created

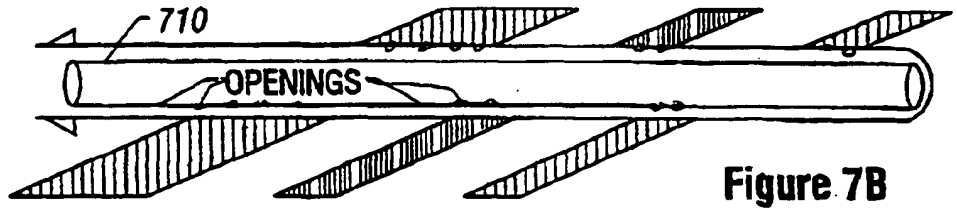

Figure 7B

High Permeability | Shale Section | High Permeability

Reservoir Inflow Control Device Is Run In Place

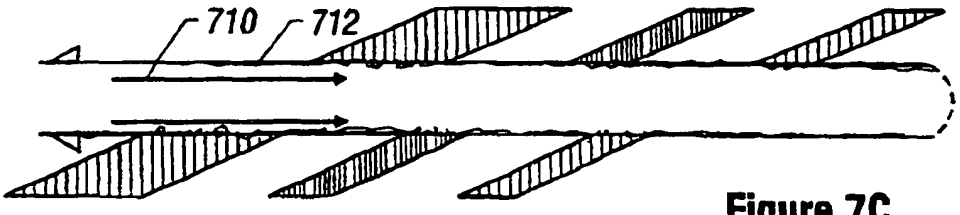

Figure 7C

High Permeability | Shale Section | High Permeability

Reservoir Inflow Control Device Is Installed
And Production Liner Can Be Run

FLOW CONTROL APPARATUS AND METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to methods of producing hydrocarbons from wellbores formed in subsurface formations and more particularly to apparatus and methods for regulating and/or equalizing production from different zones of a wellbore to optimize the production from the associated reservoirs or pay zones.

2. Background of the Art

To produce hydrocarbons from earth formations, wellbores are drilled into reservoirs or pay zones. Such wellbores are completed and perforated at one or more zones to recover hydrocarbons from the reservoirs. Horizontal wellbores are now frequently formed into a pay zone to increase production and to obtain on the aggregate higher quantities of the hydrocarbons from such reservoirs.

Sand screens of various designs and slotted liners are commonly placed between the formation and a tubing (production tubing) in the

wellbore, which transports formation fluid to the surface to prevent entry of sand and other solid particulates into the tubing. Screens of different sizes and configuration are commonly used as sand control devices. The prior art screens typically erode substantially over time. The present invention provides a screen which is less susceptible to erosion compared to prior art screens.

Excessive fluid flow rates from any production zone can cause, among other things, excessive pressure drop between the formation and the wellbore casing, relatively quick erosion of inflow devices, water or gas coning, caving, etc. Therefore, to avoid such problems, fluid flow from each production zone is controlled or regulated. Several flow control devices have been utilized for regulating or controlling production of formation fluids. One recent device passes the formation fluid through a spiral around a tubular to reduce the pressure drop before the fluid is allowed to enter the tubing. The spiral provides a tortuous path, which can be plugged at one or more places to adjust the fluid flow from the formation to the tubing. This device, although effective, must be set at the surface prior to its installation. United States Patent Application Serial No. 08/673,483 to Coon, filed on July 1, 1996, and assigned to the assignee of this application, discloses an electrically operable sliding sleeve for controlling fluid flow through a

tortuous path. This sliding sleeve may be operated from the surface. U.S. Application No. 08/673,483 is incorporated herein by reference. The present invention provides a flow control device that can be opened, closed or set at any intermediate flow rate from the surface. It also includes multiple fluid paths, each of which may be independently controlled to control the formation-fluid flow into the tubing.

In vertical wellbores, several zones are produced simultaneously. In horizontal wellbores, the wellbore may be perforated at several zones, but is typically produced from one zone at a time. This is because the prior art methods are not designed to equalize flow from the reservoir throughout the entire wellbore. Further, the prior art methods attempt to control pressure drops and not the fluid flows from each of the zones simultaneously.

The present invention provides methods for equalizing fluid flow from multiple producing zones in a horizontal wellbore. Each production zone may be independently controlled from the surface or downhole. This invention also provides an alternative system wherein fluid flow from various zones is set at the surface based on reservoir modeling and field simulations.

SUMMARY OF THE INVENTION

The present invention provides a fluid flow control device for controlling the formation-fluid flow rate through a production string. The device includes a generally tubular body for placement into the wellbore. The tubular body is lined with a sand screen and an outer shroud. The shroud reduces the amount of fluid that directly impacts the outer surface of the screen, thereby reducing the screen erosion and increasing the screen life. The fluid from the screen flows into one or more tortuous paths. Each tortuous path has an associated flow control device, which can be activated to independently open or close each tortuous path. Alternatively, flow from each path may be regulated to a desired rate.

Each flow control device further may include a control unit for controlling the output of the flow control device. The control unit may communicate with a surface control unit, which is preferably a computer-based system. The control unit performs two-way data and signal communication with the surface unit. The control unit can be programmed to control its associated device based on command signals from the surface unit or based on programs stored in the control unit. The communication may be via any suitable data communication link including a wireline,

acoustic and electromagnetic telemetry system. Each flow control device may be independently controlled without interrupting the fluid flow through the production string. The flow control devices may communicate with each other and control the fluid flow based on instructions programmed in their respective control units and/or based on command signals provided from the surface control unit.

In a preferred method, a plurality of spaced apart flow control device are deployed along the length of the horizontal wellbore. In one method of the invention, it is preferred to draw fluids from various zones in a manner that will deplete the reservoir uniformly along the entire length of the wellbore. To achieve uniform depletion, each flow control device is initially set at a rate determined from initial reservoir simulations or models. The depletion rate, water, oil and gas content, pressure, temperature and other desired parameters are determined over a time period. This data is utilized to update the initial reservoir model, which in turn is utilized to adjust the flow rate from one or more zones so as to equalize the flow rate from the reservoir.

In an alternative method, production zones are defined and flow setting for each zone is fixed at the surface prior to installation of the flow

control devices. Such a system is relatively inexpensive but would only partially equalize the production from the reservoir as it would be based on *a priori* reservoir knowledge.

The present invention provides a method of producing hydrocarbons from a reservoir having a deviated/substantially horizontal wellbore formed therein, said method, comprising: (a) placing a plurality of flow control devices in the wellbore, each flow control device set to produce formation fluid at an initial rate associated with each such flow control device; (b) determining at least one characteristic of the fluid produced through the wellbore; and (c) adjusting the flow rate through said flow control devices so as to equalize depletion of hydrocarbons from the reservoir over a time period.

Examples of the more important features of the invention have been summarized rather broadly in order that the detailed description thereof that follows may be better understood, and in order that the contributions to the art may be appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will form the subject of the claims appended hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

For detailed understanding of the present invention, reference should be made to the following detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals, and wherein:

FIG. 1 shows a horizontal wellbore having a plurality of spaced apart flow control devices for producing hydrocarbons from a reservoir according to one method of the present invention.

FIG. 2A shows a partial schematic view of a flow control device for use in the system shown in FIG. 1.

FIG. 2B shows a partial cut off view of a sand control section for use with the flow control device of FIG. 2A.

FIG. 3 shows control devices and certain sensors for use with the flow control device of FIG 2A.

FIG. 4 shows a hypothetical graph showing the flow rate from various

zones of a horiz ntal wellb r according to one method of the present invention.

FIG. 5 shows a relationship between the pressure differential and the flow rate associated with various production zones of a wellbore.

FIG. 6 shows a scenario relating to the effect of adjusting the flow rate from a production zone on production of hydrocarbons and water from such zone.

FIG. 7 shows an alternative method of equalizing production from a reservoir by a horizontal wellbore to the method of system of FIG. 1

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. 1 is a schematic illustrating a system 10 for producing hydrocarbons from a wellbore according to one method of the present invention. FIG. 1 shows a wellbore 14 having an upper casing 12 formed in an earth formation 11 according to any known method. A plurality of fluid flow devices or fluid flow devices 20a-n are placed spaced apart in the horizontal segment 14a of the wellbore 14. For the purposes of this

disclosure, a flow control device is gen rally designated by numeral 20. The construction and operation of a novel flow control device for use as the flow control devices 20 are described below in reference to FIGS 2A-B. However, for the purpose of this invention, any suitable flow control device may also be used. The spacings between the flow control devices 20 are determined based on the characteristics of the reservoir 11, as described in more detail later.

Each flow control device 20a-n includes a flow valve and a control unit. The devices 20a-n are respectively shown to contain flow regulation devices such as valves, valves 24a-n and control units 26a-n. For the purposes of this invention, a flow control device is generally designated by numeral 24 and a control unit is generally designated by numeral 26. Also, for the purpose of this invention, flow control valves 24 shall mean to include any device that is utilized to control the flow of fluid from the reservoir 11 into the wellbore 14 and control units 26 shall mean to include any circuit or device that controls the flow valves 24.

When the wellbore is in production phase, fluid 40 flows from the formation 11 into channels 22a - 22n at each flow control device, as shown by the arrow 22a'-22n'. The flow rate through any flow control devices 20 will depend upon the setting of its associated flow control valve 24. For the

purpose of illustration, the flow rates associated with the flow control devices 20a-20n are respectively designated by Q_1-Q_n corresponding to production zones Z_1-Z_n of the formation 11.

Still referring to FIG. 1, each flow control device 20a-20n or zone Z_1-Z_n may have any number of devices and sensors for determining selected formation and wellbore parameters. Elements 30a-30n respectively represent such devices and sensors corresponding to flow control devices 20a-20n or zones Z_1-Z_n. Such devices and sensors are generally designated by numeral 30. Devices and sensors 30 preferably include temperature sensors, pressure sensors, differential pressure sensors for providing the pressure drop between selected locations corresponding to the production zones Z_1-Z_n, flow rate devices, and devices for determining the constituents (oil, gas and water) of the formation fluid 40. Packers 34 may be selectively placed in the wellbore 14 to prevent the passage of the fluids through the annulus 39 between adjacent sections.

The control units 26a-26n control the operation of their associated flow control valves 24a-24n. Each control unit 26 preferably includes programmable devices, such as microprocessors, memory devices and other circuits for controlling the operation of the flow control devices 20 and for communicating with other sensors and devices 30. The control units 26

also may be adapted to receive signals and data from the devices and sensors **30** and to process such information to determine the downhole conditions and parameters of interest. The control units **26** can be programmed to operate their corresponding flow control devices **20** based upon stored programs or commands provided from an external unit. They preferably have a two way communication with a surface control system **50**. The surface control system **50** preferably is a computer-based system and is coupled to a display and monitor **52** and other peripherals, generally referred to by numeral **54**, which may include a recorder, alarms, satellite communication units, etc.

Prior to drilling any wellbore, such as the wellbore **12**, seismic surveys are made to map the subsurface formations, such as the formation **11**. If other wellbores have been drilled in the same field, well data would exist for the field **11**. All such information is preferably utilized to simulate the condition of the reservoir **11** surrounding the wellbore **14**. The reservoir simulation or model is then utilized to determine the location of each flow control device **20** in the wellbore **14** and the initial flow rates Q_1-Q_n. The flow control devices **20a-20n** are preferably set at the surface to produce formation fluids therethrough at such initial flow rates. The flow control devices **20a-20n** are then installed at their selected locations in the wellbore

14 by any suitabl method known in the art.

The production from each flow control device 20 initial equilibrium. The data from the devices 30a-30 determine the fluid constituents, pressure drops, and parameters. Based on the results of the computed param starting reservoir model is updated. The updated mode determine the desired flow rates for each of the zor substantially equalize the production from the reservoir through each of the flow control devices 20a-20n is t adjusted so as to uniformly deplete the reservoir. For exa zone starts to produce water at more than a preset valu device associated with such zone is activated to reduce t such zone. The fluid production from any zone producing be completely turned off. This method allows manipula from the reservoir so as to retrieve the most amount of a given reservoir. Typically, the flow rate from ea decreases over time. The system of the present inventio to independently and remotely adjust the flow of fluid producing zones, without shutting down production.